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Published in:
Soil Use and Management

DOI:
10.1111/j.1475-2743.2012.00408.x

First published: 23/04/2012

Document Version
Peer reviewed version

Soil Use and Management

Soil Use and Management, June 2012, **28,** 167–176 doi: 10.1111/j.1475-2743.2012.00408.x

Elemental status (Cu, Mo, Co, B, S and Zn) of Scottish agricultural soils compared with a soil-based risk assessment

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Abstract

Concentrations of six elements copper (Cu), molybdenum (Mo), cobalt (Co), boron (B), sulphur (S) and zinc (Zn) are summarized for Scottish advisory soil samples collected during the period 1996–2008. Accompanying cropping information indicated that the majority of samples collected for Co analysis were from grassland compared with B, S and Zn where sampling was predominantly prior to either potatoes or vegetables. The proportion of samples measured as potentially deficient [very low (VL) or low categories] were 80% for Co, compared with 50, 40, 38, 25 and 18% for Mo, S, Zn, Cu and B, respectively. Only S displayed a significant decline (ca. 2 mg S/kg) over this 13-year period. However, comparison of Cu and Co data with some collected from an earlier time period (1973–1980) suggested little difference for Cu but a smaller number of VL and low Co status samples. A predicted risk assessment using soil parent material, texture and drainage status suggested that 22, 38 and 40% of the agricultural area of Scotland were at a high, medium and low risk of Cu deficiency; comparable numbers for Co were 48, 30 and 22%. The reliability of the risk assessment was tested using a sub-set of advisory samples with specific information on soil series. Of the soils predicted to have a high risk of Cu deficiency, 52% actually fell into the 'deficient' status. A similar comparison for Co indicated 90% of the samples predicted as having a high risk of deficiency were measured as VL or low.

Keywords: Agricultural soil, micronutrients and sulphur, elemental status, risk class

Introduction

The soils of Scotland have developed from a range of complex geological parent materials that vary widely in composition. In the relatively young soils over much of the UK, the parent material remains the dominant factor in determining the soil trace element status (Mitchell, 1960). Ranges in topsoil 'total' element composition have been summarized for Scotland (Paterson, 2011), England and Wales (McGrath & Loveland, 1992) and Northern Ireland (Jordan *et al*., 2002). The significance of trace element related research and the major benefits that can arise from their correct management has been well demonstrated (e.g., Cakmak, 2008). Copper (Cu) deficiency is widespread and suggested to occur over 30, 25, 20, 5% of land area of Scotland, Germany, Finland and England and Wales, respectively (Sinclair & Edwards, 2008). Copper deficiency is much more likely in acid soils derived from siliceous parent material and alkaline soils derived from carbonate-rich sediments. Organic and peaty soils, reclaimed heathland sands and shallow chalk soils with moderate to high (6–12%) organic matter contents are therefore most commonly deficient in Cu in England and Wales (Archer, 1985). Trace element deficiencies in grazing livestock, particularly of Cu and cobalt (Co), have been frequently reported for soils derived from granite (Thornton & Alloway, 1974) and an early indication of the possibility of a shortage of Cu in herbage and deficiency in cattle from north-east Scotland was reported by Jamieson & Russell (1946). The significant role of 'Geochemical' (parent material), 'Biological' (availability and proportion of the total trace element content capable of being utilized by the plant) and finally 'Management' (e.g. pasture species composition and fertilizer use) related factors are therefore evident. Various

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Received November 2011; accepted after revision March 2012

site related factors will also be expected to influence any relationship that exists between the amounts of trace elements extractable in soil and herbage content (e.g. Co see McLaren *et al*., 1985). Pedological factors, such as drainage, modify the availability of trace elements by influencing the rate of weathering of soil minerals and controlling the conditions of plant uptake. Poor drainage increases the concentration of extractable trace elements compared with soils of identical parent material developed under conditions of free drainage (Mitchell *et al*., 1957). Predicting potential bioavailability is made even more complex through interactions that can exist between elements. Examples include Cu, molybdenum (Mo) and sulphur (S) (Dick *et al*., 1975; Leech & Thornton, 1987). Potential bioavailability of certain elements may, therefore, be directly influenced by a change in concentration of some other element.

The work of the Soil Survey (Soil Survey Staff, 1984), which in Scotland uses parent material and pedological drainage to group soil, provided an opportunity to develop a risk-based assessment of trace element concentrations. The probable occurrence of deficient to adequate levels of 'available' trace elements using subsoil (B horizon) total contents in conjunction with information on pedological drainage conditions, texture and geological nature of parent material was reported in 1982 (COSAC/SARI, 1982). A preliminary assessment of this risk-based approach was made at the time by comparisons with topsoil, Scottish Agricultural College (SAC) advisory data, and further testing was recommended but never attempted until now. There were data summaries produced for two specific areas of Scotland; Orkney (Dry & Sinclair, 1985) and Caithness (Towers & Sinclair, 1986), and further data are summarized in the current paper. Since the 1982 report was published, more soil series have been identified, which, when coupled with tremendous progress in digital mapping and a continuing awareness of the health implications of trace elements in feed and food quality, make a re-assessment and update timely. Here, we summarize 13 years of soil fertility tests carried out by the SAC advisory laboratories (1996–2008) for the elements Cu, Co and Mo making a brief comparison with the original data together with additional elements Zn, S and B, and use a case study to test the validity of the original risk assessment approach. Analysis of trends in soil fertility over time has been carried out for major nutrients using data from commercial laboratories, for example, Wheeler *et al*. (2004) but long-term trends in microelement status of soils are rarely published.

Material and methods

Soil advisory data

Three groupings of advisory data have been utilized in this paper. The original data (Cu, Co and Mo) used for the 1982 report were collected during 1973–1980 from West of Scotland Agricultural College and North of Scotland College of Agriculture areas and for samples collected during 1968–1977 for the East of Scotland College of Agriculture area. A second group of data from soils collected during 1985 included details of soil series and farm type with each advisory sample. These data have been used to evaluate the accuracy of the soil-based risk assessment. Farm type has been defined using the proportion of grass, with some indication of intensity achieved using the amount of N applied (less or greater than 125 kg N/ha/year). The final, and largest, group with data for six elements (Cu, Co, Mo, B, S and Zn) contains a total of ca. 14 000 individual soil samples, half (6867) having only a single trace element determinand, while 4563 soil samples had two and 563, 1762, 192 and 12 had 3, 4, 5 and 6 determinands, respectively. For many of these records, additional information is available, including agricultural area office and postcode, from which some spatial context can be obtained, together with management factors, such as, previous and next crop. The collection of this data has varied over time and also between agricultural area offices, but roughly 80% of the total number of samples has some form of accompanying information (Table 1). Unfortunately, collection of soil series and farm type was stopped during 1987 and necessitated a modified approach to matching soil sample to geographical location using the less precise post code. The possibility that individual post codes could be associated with multiple samples exists, and because the post code identifies the main farm/business centre, there is the possibility that samples may have been collected from elsewhere. Figure 1 shows the distribution of samples based on post code and, as would be expected, displays a strong spatial pattern linked to agriculturally managed soil. While various possible shortcomings can be raised with the use of advisory data (e.g. lack of any structured sampling programme and a bias towards problem situations), this large data set can provide a unique insight into the spatial and temporal trends in extractable trace elements. The cropping information also provides a mechanism for a broad separation into main land use types, arable and grassland (livestock). Unfortunately, the

Table 1 Total number of samples (1996–2008) for each element and level of accompanying information

Element	Number of samples	% with postcode	% with next crop details
Cu	10140	84	87
Mo	79	84	66
Co	1102	77	80
B	3084	79	73
S	7822	82	80
Zn	3535	84	76

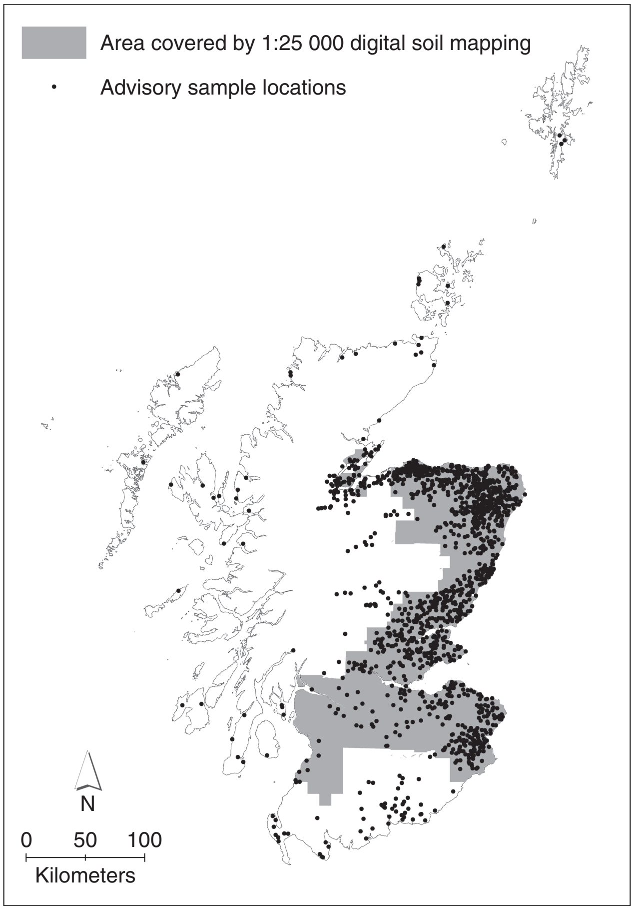

Figure 1 Advisory soil sample distribution together with the area (grey) where detailed soil series information is available.

variable quality of accompanying information and differences in numbers of samples collected annually and for individual elements make statistical analysis difficult. On some occasions, results for Mo and Co have had to be omitted because of low sample numbers.

Soil series risk classes

The risk of trace element deficiency occurring in herbage is predicted by a series of decision rules established in the original report (COSAC/SARI, 1982). Starting with typical total concentrations in soil B horizons, drainage and/or textural information is used to assign risk classes from low to high (very high for Mo, in relation to the risk of interfering with uptake of other nutrients) on a soil series basis. The Scottish soil classification recognizes groups of soils formed on the same underlying parent material as 'associations' (Soil Survey Staff, 1984) with drainage characteristics further subdividing these into 'series'. The 1982 report has classes for ca. 450 series, mostly those found in agricultural areas. Occasionally, a series is given a risk class for one element, but not for another. Although soils have been mapped across the whole of Scotland at the series level, the maps have only been digitized for a limited area but do cover most of the agriculturally important soils. Within this area, there are ca. 750 soil series. Therefore, ca. 300 series required to have risk classes assigned. A number of techniques were used to fill in missing values:

1. Some associations have a risk class for one series, but nothing for a second series with the same major soil subgroup; the same class is assigned.
2. Where analytical data are available for B horizons from the missing series across the country, an assessment of the range of values was made and combined with the drainage status to assign a class using the rules based on soil parent material and pedological drainage.
3. For some series, analogues from other associations with similar properties were used.
4. For associations with multiple missing series, if no other method of estimating a risk class was found, they were given the highest class found in that association (precautionary principle).
5. For 'problematic' series, for example, complexes, series, which are the only one in an association, etc., then the highest class is assigned. Fortunately, these series have limited geographical extents.

A spatial overlay of the derived risk classes for Cu and Co was produced in ArcGIS using the digitized 1:25 000 soil survey map, and individual areas determined. The relationship between the derived risk classes for Cu of the soil polygon, which lies under each sample point, defined by the post code, was also determined. The location of a proportion of sampling points was outside the area covered by the digitized map and so no comparison could be carried out for these. In addition, some samples were not determined for Cu and others had multiple samples for the same post code. In this case, a single averaged value was used. Having filtered out these samples, ca. 1000 samples remained.

Analytical methods

The soils (< 2.0 mm air-dried) were extracted with 0.43 M acetic acid for Co on soil shaken for 16 h using a soil/solution ratio of 1:20 (w/v); 0.05 M EDTA (adjusted to pH 7 with NH_4OH) using a soil/solution ratio of 1:5 (w/v) for Cu and Zn; 1 M (neutral) ammonium acetate for Mo on soil shaken for 16 h using a soil/solution ratio of 1:16 (w/v); boiling distilled water under reflux for 10 min using a soil/solution ratio of 1:2 (w/v) for B; and on shaking with 500 μg/mL P solution of potassium dihydrogen phosphate for 1 h using a soil/solution ratio of 1:5 (w/v) for S.

Two classification systems have been used over the time period since 1982; the original three classes are shown in Table 2 and the current system is shown in Table 3. While the majority of advisory data is summarized using the current

Table 2 Summary of the original classification (COSAC/SARI, 1982)

	mg/kg air-dry soil			mg/kg air-dry soil
Soil status	Co	Cu	Soil status	Mo
Deficient (D)	< 0.3	< 0.8	Normal (N)	< 0.05
Borderline (B)	0.3–0.4	0.8–1.5	Superabundant (S)	0.05–0.1
Adequate (A)	> 0.4	> 1.5	Potentially toxic (PT)	> 0.1

Table 3 Current SAC interpretative scales for extractable concentrations (mg/kg) of non-NPK nutrients in soil (based on MISR/SAC, 1985)

	Very low	Low	Moderate	High	Excessive
Element	Deficiency probable	Deficiency possible	No deficiency expected	No risk of deficiency	Crop toxicity may occur
Cu	< 1.0	1.0–1.6	> 1.6–8.5	> 8.5–80	> 80
Mo	< 0.01	0.01–0.04	> 0.04–0.08	> 0.08–0.2	> 0.20
Co[a]	< 0.20	0.20–0.65	> 0.65–0.94	> 0.94	–
B	< 0.3	0.3–0.5	> 0.50–1.0	> 1.0–3.5	> 3.5
S	< 3.0	3.0–6.0	> 6.0–10.0	> 10.0	> 50
Zn	< 0.5	0.5–1.5	> 1.5–10	> 10–80	> 80

[a]Imperfect pedological drainage.

Table 4 Extractable Cu status (see Table 3) collected during 1985 and grouped according to risk class defined for individual samples using soil series information collected at the time of sampling.

	Risk of Cu deficiency		
Extractable Cu (mg/kg)	High	Moderate	Low
Deficient < 1.6 (157)	52.1	29.3	15.2
Deficiency unlikely 1.6–8.5 (243)	45.2	60.2	63.6
No risk of deficiency > 8.5 (38)	2.7 (146)	10.4 (259)	21.2 (33)

Data are shown as proportions (%) of the total number of samples shown in brackets.

five class interpretive scale (Table 3), direct comparisons between the original and current advisory data use the three class system (Table 2).

Results

Evaluation of soil-based risk assessments

During 1985, additional information on soil series was collected with advisory soil samples and a total number of 438 and 345 samples have been used to test the soil series–based risk assessment for Cu (Table 4) and Co (Table 5), respectively. Of the 146 samples that were predicted as having a high risk for Cu deficiency, then more than half (52%) were actually measured as being deficient, with 45% unlikely to show deficiency and < 3% of samples no risk. The pattern for moderate (M) and low (L) predicted risk classes was an increasing proportion of soils being measured as having little or no risk of deficiency. For Co, 90% of samples predicted to have a high risk of being deficient were measured as having very low (VL) or L extractable concentrations (Table 5). The general trend was an increase in the extractable Co concentrations for M and L risk categories.

Table 5 Extractable Co status (see Table 3) collected during 1985 and grouped according to risk class defined for individual samples using soil series information collected at the time of sampling.

	Risk category		
Extractable Co (mg/kg)	High	Moderate	Low
VL < 0.19 (66)	25.8	8.5	0.0
L 0.2–0.59 (230)	64.2	59.6	82.8
M + H > 0.6 (49)	10.0 (240)	31.9 (47)	17.2 (58)

Data are proportions (%) of the total number of samples shown in brackets.

Table 6 Comparison of risk classes with measured values of Copper and Cobalt identified through post code for the soil sample

	Copper		Cobalt	
	No. of samples	%	No. of samples	%
Match	387	38.7	69	30.4
Overestimate	569	56.9	121	53.3
Underestimate	44	4.4	37	16.3

The second and, because of the need to employ post codes, less precise test of the soil-based risk prediction was made for Cu and Co (Table 6). The general pattern was similar for both these elements with approximately a third of results from soil samples matching the predicted risk class, while for half the samples, the predicted risk was overestimated compared with the measured concentration (Table 6). Less than 5 and 17% of Cu and Co samples, respectively, had their risk assessments underestimated.

Relationship between copper status and farm type

A summary of soil Cu status by farm type for samples collected in 1985 is shown in Figure 2 where some differences are apparent. A significant proportion (40%) of samples collected from arable farms had either a VL or L Cu status. On grass dominated farms, a large difference was apparent between the two N regimes; the farms using high N had ca. 10% of samples having a VL or L status, which

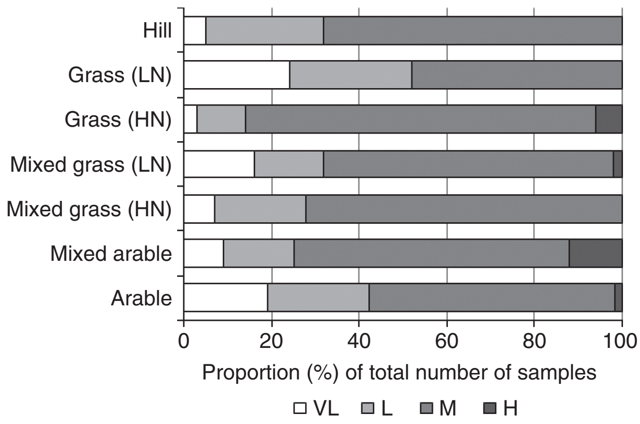

Figure 2 Relationships between farm type and extractable soil copper status expressed as a proportion (%) of the total number of samples sub-divided according to farm type (where farm type has been defined as arable (< 20% of grass) 328, mixed arable (21–40% grass) 523, mixed grass (41–80% grass moderate – high nitrogen) 112, mixed grass (41–80% grass low nitrogen) 110, grass (> 90% grass nitrogen) 39, grass (> 90% grass moderate – high nitrogen) 21, Hill 37) for samples collected during 1985. High (HN) nitrogen > 125 kg N/ha/year and low (LN) N < 125 kg N/ha/year.

compared with > 50% for those farms applying lower rates of N grassland. The grass receiving more N is likely to be located on lower lying ground with better soils than the grassland receiving smaller amount of N although this cannot be substantiated from the data. The samples from hill farms appear to be comparable with the other farms, but this probably reflects a preferential sampling regime from the lower lying, better soils and higher productivity in-by areas.

Summary of 1996–2008 advisory data

With over 10 000 soil samples, Cu was the most frequently analysed element, followed by S, Zn, B, Co and Mo (Table 7). A quarter of samples had either a VL or L Cu status compared with ca. 40% for S and Zn. Eighty percent of Co analysis were classed as having a VL or L status, and of the 79 samples analysed for Mo 60% had a VL or L status. The proportion of total samples classed as having a M status was wide and declined in the order Cu > B > Zn > S > Mo > Co.

Table 7 Summary of the advisory data (1996–2008) for six elements expressed as a proportion of the total number of samples

	Cu	Mo	Co	B	S	Zn
Total number	10140	79	1102	3084	7822	3535
Status	% of the total number of samples					
EH	0.0	3.8	0.0	0.3	0.8	0.0
H	2.5	22.8	7.4	16.5	26.2	4.0
M	71.1	20.3	13.1	65.5	33.7	58.3
L	19.7	39.2	61.3	15.5	32.6	36.2
VL	6.7	13.9	18.3	2.2	6.8	1.4

A comparison of sample numbers collected in relation to information on previous and next crop (Figure 3) showed an essentially similar pattern for Cu and Co while there was a definite preference for sampling prior to the major cash crops of potatoes and vegetables for B, S and Zn. Over 60% of the samples analysed for Co were collected from grassland reflecting the concern over herbage quality.

Individual elements appeared to display a similar pattern when the proposed next crop information was used to group the data (Figure 4). As described previously (Table 7), individual elements did differ in their overall status. The distribution of Cu concentrations (Figure 4a) were similar irrespective of the next crop, with the largest difference between autumn sown crops and grass where 20 and 35% of samples were categorized as being VL plus L, respectively. More than 60% of samples had a M Cu status. One particular striking feature was the 80% of samples collected from grassland, which had either a VL or a L Co status (Figure 4b). The pattern for B was very similar with the majority of samples having a moderate status with 15–20% being deficient (Figure 4c). Interestingly, the only samples having an excessive B status were collected from vegetable growing areas. Extractable S showed a small number of samples falling into the M class with significant numbers (ca. 40%) being deficient but also > 20% in the high category (Figure 4d). Over half the 1140 samples collected prior to potatoes fell into the VL or L categories for Zn (Figure 4e) the comparable proportion for soil samples collected directly after potatoes was 20%, although this is for a much smaller number of samples (57).

The comparison of soil extractable Cu, B, S and Zn concentrations for samples collected either before or after the main crop types is shown in Figure 5. With respect to Cu, concentrations were very similar with significant differences (higher concentrations) only being apparent for samples collected after either vegetables or fodder crops. For B, the only difference was a significantly higher averaged concentration when the previous crop was vegetables. A greater variability in averaged S concentrations was apparent between cropping groups (Figure 5) and while winter and spring crops had similar concentrations after fodder crops, vegetables and potatoes were higher. The groupings for Zn also showed higher concentrations for samples collected after fodder, potato and vegetable crops.

Changes with time

Changes over time were only apparent for S and while there was some variability between years a decline of ca. 2 mg/kg in extractable S status was apparent over the 13-year period

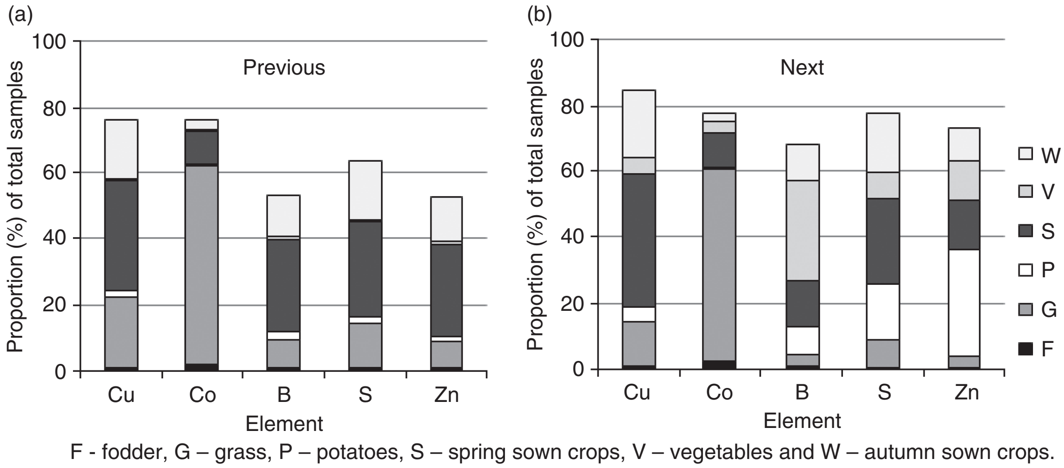

Figure 3 Proportion of total number of samples (Cu 10140, Co 1102, B 3084, S 7822 and Zn 3535) with pervious (a) and next (b) cropping information for five elements (Mo not shown because of low sample number).

(which equates to 0.15 mg S/kg/year). The change in S concentrations is also evident from analysis of S status (Figure 6) where the relative proportion of soils in the VL and L status categories increases with time from ca. 20% in 1996 to 40% in 2008. There were no time trends distinguishable for any of the other elements.

Comparison between original and current advisory soil data sets

Comparison between the original data and the more recent set (Table 8) suggests that the proportion of soil samples deficient in Co and Cu has declined by ca. 25%. This general trend appears to be common for each geographical area. Any trend for Mo is less apparent because of the low sample numbers.

Discussion

Analysis from soil samples collected for advisory purposes in Scotland were collated and summarized for various time periods to quantify the current micronutrient status of Scottish soils managed for agriculture. Accompanying information collected at the time of soil sampling included previous and next crop, post code and for a single year, farm type and soil series. The pattern of soil sampling in relation to cropping information showed a clear emphasis for B, S and Zn to be requested prior to potatoes and vegetables. Knowledge of the Zn status can help in the management of powdery scab (Burnett *et al.*, 1990; Burgess *et al.*, 1992). Where extractable soil concentrations are ≤5 mg Zn/kg SAC potato specialists then suggest the greater risk of powdery scab would mean a variety resistant to powdery scab should be selected. Of the 1139 samples for Zn analysis collected prior to potatoes, >90% fell below this value. A pot study by Burnett & Wale (1993) indicated that the effectiveness of Zn for the control of powdery scab is related to the level of inoculums present in soil. Extractable S was particularly high after potatoes, possibly because of a combination of sulphuric acid used to burn off haulms and potassium sulphate in the manufactured fertilizer. The frequency of B analysis prior to vegetables reflects the general susceptibility of brassicas and swedes to B deficiency (Linse *et al.*, 2011). Extractable concentrations of B were generally higher after fodder crops and vegetables, which reflect recommendations from Litterick *et al.* (2009).

The emphasis for Co analysis on grassland reflects the concern for deficiencies in grazing livestock (see, for example, Fisher, 2008). Predicting Co deficiencies from either soil or herbage analysis is not straight forward (Paterson *et al.*, 1991). Identifying deficiencies for grazing animals should involve two distinct steps (Suttle *et al.*, 2003): an accurate prediction of plant uptake through a soil extraction method, followed by that extraction accurately predicting Co intake by the grazing animal. Advantages in using soil rather than herbage to predict risk of Co-deprivation exist because of the notoriously variable Co concentrations measured in herbage (Paterson *et al.*, 1991). As with Co, soil and herbage levels are also poor indicators of Cu deficiency (Fisher, 2008). However, the large number of samples analysed for Cu possibly reflects its importance not only for animal health but also for crop yield and quality (Malhi & Karamanos, 2006). Although only a small number of samples were analysed for Mo, 60% of these had VL or L status. Deficiency of Mo is considered relatively rare in agricultural plants (Kaiser *et al.*, 2005); however, excess Mo can cause livestock health issues by depressing the availability and absorption of Cu (Fisher, 2008).

There was an indication that extractable S concentrations had declined over time (Figure 6) resulting in an increase in

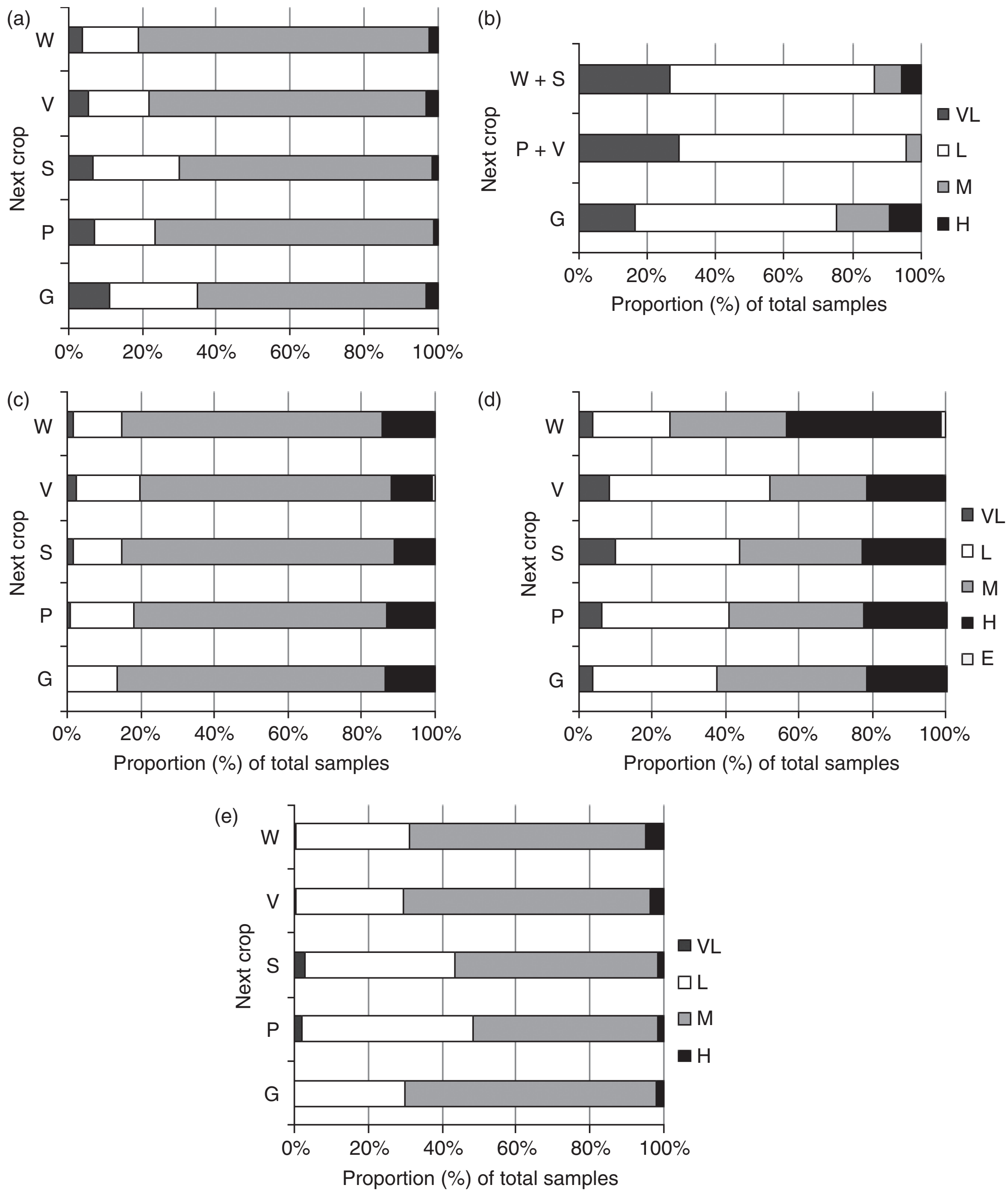

Figure 4 A summary of soil status for (a) Cu, (b) Co (c) B (d) S and (e) Zn grouped according to the proposed next crop. Where G, grass; P, potatoes; S, spring sown crops; V, vegetables and W, autumn sown crops.

the relative proportion of soils in the VL and L S status categories from ca. 20% in 1996 to 40% in 2008. McGrath & Zhao (1995) predicted that 11% of the UK land area was at high risk of S deficiency for cereals, and a further 22% at medium risk during the mid 1990s. The high-risk areas were in south-east Scotland, the Scottish Borders, East Anglia, the Welsh Borders and south-west England. A continuing decrease in soil S status was also predicted as a consequence of declining atmospheric deposition, which halved during the period 1979–1993 (Downing *et al*., 1995).

The initial emphasis of micronutrient research undertaken in Scotland included complementary work being undertaken at the various research institutions, including, Macaulay Institute for Soil Research (MISR, now James Hutton Institute http://www.hutton.ac.uk/) and Scottish Agricultural Colleges (now part of SAC http://www.sac.ac.uk/). An early recognition that a significant geochemical relationship exists with soil micronutrient content, together with a national soil survey that classified soils according to their parent material and drainage status, led to the development of a risk

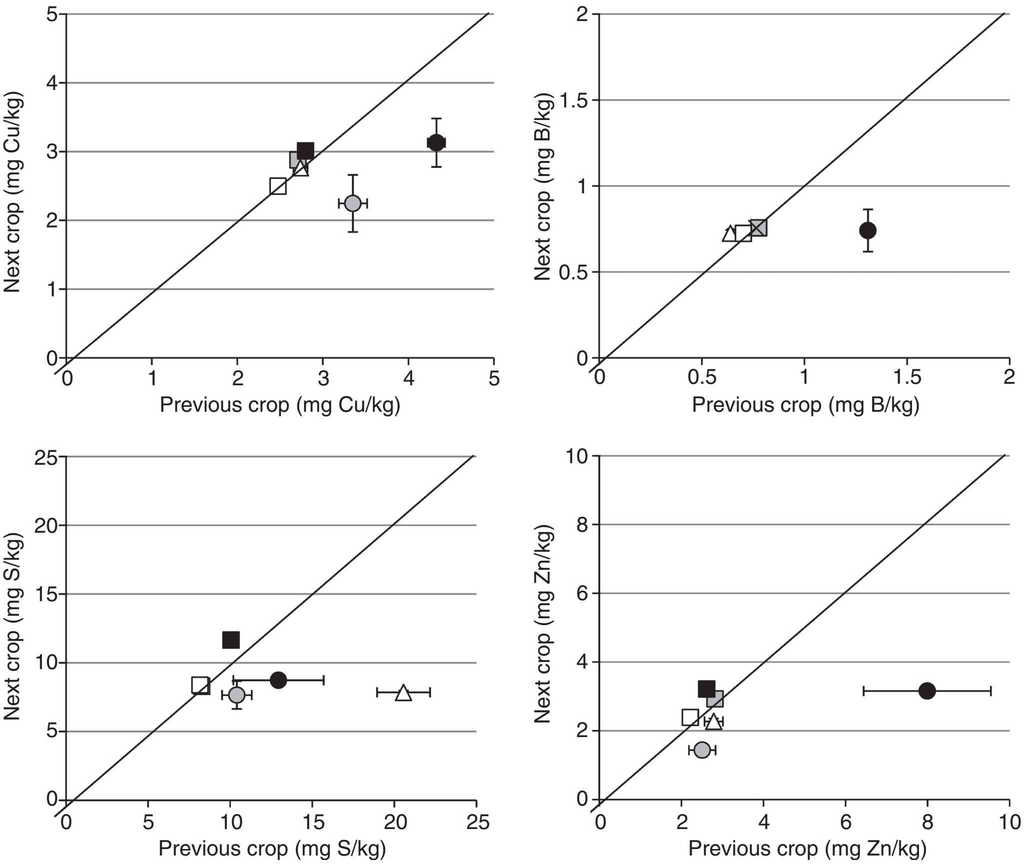

Figure 5 Difference between averages calculated for soil extractable elements (Cu, B, S and Zn) sampled before or after individual crops together with the standard errors. The unity line is also indicated and points falling below this mean a higher concentration after a particular crop compared with values above the unity line suggests a lower average concentration compared with the previous crop.

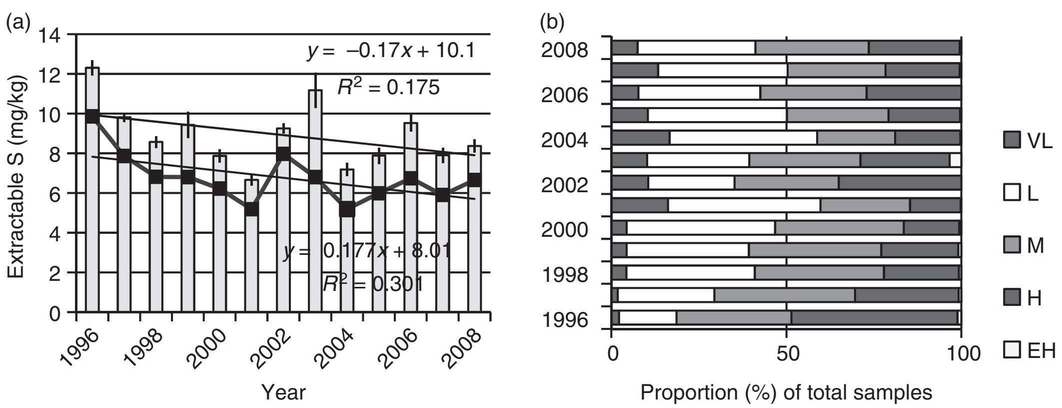

Figure 6 Change in (a) annual mean (bar including SE) and median (line) values together with (b) S index for extractable S over time. The regression lines are linear.

assessment. The original risk assessment was developed around 1980 and employed information on soil association (parent material) and soil series (pedological drainage) (Berrow *et al*., 1983). Using data from advisory soil samples collected during 1985 with accompanying soil series, information allowed a direct test of the accuracy of the risk assessment. The comparison was good for measured extractable Co and reasonable with Cu. Importantly, the risk assessment did not under predict potential deficiencies and it is possible that higher than predicted concentrations of

Table 8 Summary of cobalt, copper and molybdenum status of soils for samples collected during 1973–1980 from West of Scotland Agricultural College (WOSCA) and North of Scotland College of Agriculture (NOSCA) areas and for samples collected during 1968–1977 for the East of Scotland College of Agriculture (ESCA) area.

	No. of samples	Old data (1973–1980) A	B	D	No. of samples	New data (1996–2008) A	B	D
Co								
NOSCA	3234	34	19	47	562	47	15	38
WOSCA	1191	35	22	44	151	43	23	34
ESCA	4484		42[a]	58	389	52	18	31
Cu								
NOSCA	3536	69	23	8	8177	77	20	3
WOSCA	1227	88	9	3	326	81	17	2
ESCA	5458		90[a]	10	1637	78	18	5
Mo		PT	S	N		PT	S	N
NOSCA	1186	7	12	81	54	17	11	72

[a]A + B. Data are expressed as a proportion (%) of the total number of samples. A, adequate; B, borderline; D, deficient; PT, potentially toxic; S, superabundant; N, normal. Classification is according to the categories shown in Table 2.

extractable Cu might be the result of long-term fertilizer applications. This allowed a regional/national scale extrapolation to be made with reasonable confidence using digitized soil information at the scale of 1:25 000 (Figure 1). When made it was estimated that 22, 38 and 40% of the agricultural area of Scotland is at a high, medium and low risk of Cu deficiency; comparable numbers for Co were 48, 30 and 22%, respectively. This compared reasonably with the proportion of the advisory data falling into the VL plus L categories of 25 and 80% for Cu and Co, respectively. The future emphasis will be to develop and test a similar risk-based approach for B, S and Zn.

Conclusions

A summary of recent (1996–2008) data for six elements extracted from Scottish agricultural advisory topsoil indicated a variable but significant number of potential deficiencies. More than three quarters of soil collected from grassland were deficient in Co, while ca. 40% of samples were potentially deficient in S, 25% indicated Cu deficiency compared with 18% for B and 50% of the small number analysed for Mo. More than 90% of the 1139 samples collected prior to potatoes fell below a concentrations of < 5 mg Zn/kg, which has been linked with an increased risk of powdery scab. Only extractable S indicated a possible decline in soil status over the 13-year period. Comparisons made between an older set of data (1973–1980) suggested little change in Cu status compared with a slight improvement in Co status. A risk-based assessment that employed soil parent material, texture and drainage status was applied to the ca. 750 individual soil series contained within the digitized area of Scotland, containing the majority of the agriculturally important soils. The prediction was that 22, 38 and 40% of this area were at a high, medium and low risk of Cu deficiency; comparable numbers for Co were 48, 30 and 22%. Using data collected for a single year (1985), where both extractable Cu and Co together with site specific information that included soil series were available, the accuracy of the risk assessment could be tested. The comparison for Co was very good with 90% of the samples predicted as having a high risk of deficiency being actually measured as VL or low. The figure was lower for Cu with just over half the samples predicted to have a high risk of Cu deficiency falling into the 'deficient' status. This under prediction may reflect the residual influence of repeated Cu applications.

Acknowledgements

Funding was provided by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas) and the Scottish Government (RESAS). The help of the following are acknowledged: Mr Al Gay in extracting the advisory soil data, the large number of SAC advisory and laboratory staff, Soil Survey Staff involved in collecting the various samples and data over the years.

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